ESL-TR-85-08

AdA183858

Stabilized Pavements for ALRS Summary Report

MARSHALL R. THOMPSON

ROBERT R. COSTIGAN

UNIVERSITY OF ILLINOIS
DEPARTMENT OF CIVIL ENGINEERING
URBANA, ILLINOIS 61801

JUNE 1985

FINAL REPORT

APRIL 1982 - JANUARY 1985

20061003328

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

AIR FORCE ENGINEERING AND SERVICES CENTER

AFESC

ENGINEERING & SERVICES LABORATORY
AIR FORCE ENGINEERING & SERVICES CENTER
TYNDALL AIR FORCE BASE, FLORIDA 32403

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)
ESL-TR-85-08

6a. NAME OF PERFORMING ORGANIZATION
Department of Civil Engineering
University of Illinois

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION
Air Force Engineering and Services Center (RDCR)

6c. ADDRESS (City, State and ZIP Code)
Urbana, Illinois 61801

7b. ADDRESS (City, State and ZIP Code)
Tyndall AFB FL 32403-6001

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
FY8952-82-60024

8c. ADDRESS (City, State and ZIP Code)

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
64708F	2621	40	05

11. TITLE (Include Security Classification) Stabilized Pavements for ALRS -Summary Report

12. PERSONAL AUTHOR(S)
Dr Marshall R. Thompson and Maj Robert R. Costigan

13a. TYPE OF REPORT
FINAL

13b. TIME COVERED
FROM Apr82 TO Jan85

14. DATE OF REPORT (Yr., Mo., Day)
June 1985

15. PAGE COUNT
37

16. SUPPLEMENTARY NOTATION
"Availability of this report is specified on reverse of front cover."

17. COSATI CODES

FIELD	GROUP	SUB. GR.
13	02	
08	13	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Airfields Soil Mechanics
ALRS Soil Stabilization
Stabilized Pavements Alternate Launch and Recovery Surfaces

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

An "ALRS Stabilized Material Pavement Analysis System" (SPAS) is proposed. An "intact slab" approach based on ILLI-PAVE analyses and Meyerhof ultimate load concepts is recommended. A design process for inverted ALRS pavements is also presented. The study of the WES Test Section data indicated the validity of SPAS and facilitated the development of transfer function concepts relating ALRS pavement response to performance.
Inputs required to establish the stabilized base thickness for an ALRS pavement (F-4 loading) are the field strength of the stabilized material and the E_{Ri} (measure of resilient modulus) of the fine-grained subgrade. A properly designed ALRS pavement for F-4 loading can accommodate a reduced number of C-130 and F-15 load applications. The SPAS thickness design concepts (based on an intact slab approach) are applicable to a broad range of cementitious-stabilized materials (soil-cement, lime-fly ash-aggregate, soil-lime mixtures, similar high-strength and modulus materials).

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
DAVID F. RUSCHMANN, Capt, USAF

22b. TELEPHONE NUMBER (Include Area Code)
(904) 283-6329

22c. OFFICE SYMBOL
HQ AFESC/RDCR

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

This summary report was prepared by the Department of Civil Engineering, University of Illinois @ Urbana-Champaign, Illinois under contract FY8952-82-60024, for the Air Force Engineering and Services Center Engineering and Services Laboratory, Tyndall Air Force Base, Florida.

Research contained in this report was conducted between April 1982 and January 1985. AFESC RD Project Officers were Captain D. Ruschmann, J.D. Wilson and H. Kelly.

This report is a summary of a four-phase effort and proposes analysis methods and design concepts based on the previous work. The major thrust of the previous efforts and this technical report was completed by Maj R. R. Costigan as a part of his doctoral thesis. This report summarizes that thesis. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the U.S. Air Force. This report does not constitute a standard, specification, or regulation.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

This technical report has been reviewed and is approved for publication.

David F. Ruschmann
DAVID F. RUSCHMANN, Capt, USAF
ALRS Project Officer

W.S. Strickland
W.S. STRICKLAND
Chief, Rapid Runway Repair

Everett L. Mabry
EVERETT L. MABRY, Lt Col, USAF
Chief, Engineering Research Division

Robert E. Boyer
ROBERT E. BOYER, Col, USAF
Director, Engineering and Services Laboratory

(The reverse of this page is blank)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

(The reverse of this page is blank.)

SECTION I

INTRODUCTION

The USAF's Rapid Runway Repair (RRR) Research and Development Program contains a program component called Alternate Launch and Recovery Surfaces (ALRS). General requirements for ALRS are (1) a 20-year design life, (2) capability of accommodating 150 passes of an F-4 and 25 C-130 passes at any time, and (3) low cost. During the conduct of the research program, the consideration of the F-15 at increased wheel loads and tire pressures was incorporated.

The F-4 design wheel load is 27 kips with an average contact pressure of 265 psi. The radius of an equivalent circular tire contact area is 5.7 inches.

C-130 maximum single-wheel loading is 42 kips with a tire contact pressure of 95 psi. The radius of an equivalent circular contact area is approximately 12 inches. Center-to-center tandem spacing is 60 inches. The equivalent single-wheel load is approximately 42 kips.

Possible increased F-15 wheel-loading conditions are 30 kips with a 355 psi contact pressure and 36 kips with a 400 psi contact pressure. The radii of the equivalent circular contact areas are 5.18 inches (30-kip loading) and 5.35 inches (36-kip loading).

Pavements containing stabilized soil layers demonstrate significant potential for ALRS applications. Many studies and field experiences have demonstrated that stabilized material (soil-lime, soil-cement, lime-fly ash-aggregate) pavement sections can support ALRS-type traffic requirements. Stabilized layers can be used as:

1. A base course for a conventional pavement (AC surface + stabilized base);
2. A subbase for an inverted pavement (AC surface + granular base + stabilized subbase); or
3. Modified subgrade (working platform) to facilitate the construction of a conventional flexible pavement (AC surface + granular base over modified subgrade layer) in which no structural credit is given to the stabilized layer.

The low-cost requirement places a premium on the use of the best technology in developing material requirements and pavement thickness design concepts for ALRS. The 100 percent availability requirement for accommodating the aircraft passes means that under the worst circumstances (freeze-thaw (F-T)-softened subgrades; high water tables; maximum possible F-T stabilized material strength reductions, etc.), a satisfactory pavement structural capacity and acceptable levels of pavement surface geometry (ruts, roughness, etc.), a satisfactory pavement structural capacity and acceptable levels of pavement surface geometry (ruts, roughness, etc.) must be provided to meet ALRS requirements.

A four-phase research effort was conducted to provide the structural design, pavement response and performance, and environmental factor technologies needed to facilitate the development of a comprehensive system for considering ALRS-stabilized material applications. The various phases were:

Phase I: Structural Considerations

Phase II: Environmental Factors Study

Phase III: Develop Preliminary ALRS Stabilized Soil Pavement Analysis System (SPAS)

Phase IV Pavement Test Section Review

Activities and findings from the separate phases are summarized in this report. Conclusions and recommendations are presented.

SECTION II

SUMMARY OF ACTIVITIES AND FINDINGS

A. PHASE I - STRUCTURAL CONSIDERATIONS

Only cementitious stabilizers (cement, lime, lime-fly ash) were considered. Cementitious stabilizers typically increase compressive strength, shear strength (large increase in cohesion), tensile strength (flexural and split tensile), and modulus of elasticity. Freeze-thaw and moisture resistance are also significantly enhanced by stabilization. If the stabilized materials are of structural layer quality, the controlling thickness design criterion for the stabilized material is generally the flexural stress at the bottom of the layer. A summary of the strength, modulus, and fatigue properties of cementitiously stabilized materials was prepared and included in a previous project report (Reference 1).

In the mechanistic design concept, a structural model is used to calculate pavement responses (stresses, deflections, strains). Transfer functions are required to relate pavement response to pavement performance. Typical transfer function response parameters are surface deflection, radial tensile strain in the asphalt concrete layer(s), subgrade stress and/or strain, and radial tensile stress in the stabilized base. For high strength and modulus stabilized materials, a "fatigue approach" is frequently used to relate stress ratio (S = radial tensile stress/flexural strength) to number of load applications to failure (usually defined as initial cracking of the stabilized layer).

The structural behavior of typical ALRS pavement systems (shown in Figure 1) was characterized using ILLI-PAVE, ILLI-SLAB, and Meyerhof Ultimate Load concepts. A broad range of stabilized material moduli, stabilized layer thicknesses, and subgrade strength was considered.

1. ILLI-PAVE Results

The complete ILLI-PAVE data base was presented in a previous project report (Reference 1). Design algorithms for the F-4 were developed based on statistical analyses of the ILLI-PAVE data. The algorithms (for interior loading) are shown in Table 1. The major factor controlling flexural stress (the primary thickness design criterion) is stabilized layer thickness. Subgrade E_{Ri} has a very limited influence.

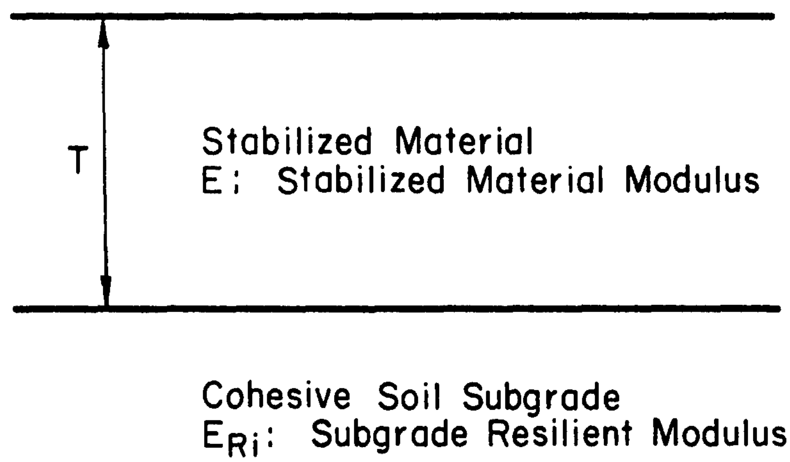

Figure 1. Typical ALRS Stabilized-Base Section Pavement.

TABLE 1. ILLI-PAVE ALGORITHMS FOR ALRS STABILIZED LAYERS (INTERIOR LOADING)

For $E < 500$ ksi:

$\sigma = 405 - 18.68T - 3.49\ E_{Ri}$

$R^2 = 0.868 \quad SEE = 26.0$

$\mathrm{Log}\sigma = 2.987 - 0.0634T - 0.0116\ E_{Ri}$

$R^2 = 0.937 \quad SEE = 0.058$

For $E > 500$ ksi:

$\sigma = 510 - 24.77T - 1.48\ E_{Ri}$

$R^2 = 0.914 \quad SEE = 26.2$

$\mathrm{Log}\sigma = 3.086 - 0.0668T - 0.00351\ E_{Ri}$

$R^2 = 0.982 \quad SEE = 0.031$

E_{Ri} = Resilient modulus of cohesive subgrade soil (repeated deviator stress = 6 psi)

T = Stabilized layer thickness, inches

E = Modulus of stabilized layer, ksi

σ = Flexural stress (interior loading) at bottom of stabilized layer, psi

R^2 = Coefficient of determination

SEE = Standard error of estimate

F-15 loading is greater than the F-4 and, therefore, increases the flexural stresses. The F-15 30-kip load stabilized base course flexural stresses are approximately 19 percent greater than the F-4 stresses and the F-15 36-kip load increases (relative to the F-4) are approximately 41 percent. Note that the load ratio for the F-15 at 30 kips is 1.11 (30/27) and 1.33 (36/27) for 36-kip loading.

C-130 loading effects (42-kip wheel load, 95 psi contact pressure) were considered by comparing F-4 and C-130 wheel load-induced flexural stresses for typical ALRS-stabilized base pavements. The C-130 stabilized base course flexural stresses and subgrade deviator stresses are approximately 10 percent greater than the F-4 stresses.

2. ILLI-SLAB Results

ILLI-SLAB, a versatile finite element slab model (varied load locations, nonuniform slab thickness and k, joint modelling, etc.), has been developed at the University of Illinois. In a recent AFOSR study (Reference 2) at the University of Illinois, ILLI-SLAB was modified to permit the consideration of a stress-dependent subgrade. The concept of a resilient modulus of subgrade reaction (K_R) was developed.

ILLI-SLAB analyses (interior loading conditions, F-15 loading) were conducted for a wide range of conditions (E, base modulus; T, base thickness; k, modulus of subgrade reaction). The slab size was 12 feet wide by 15 feet long. Zero load transfer between slabs was assumed.

A summary of the maximum flexural stresses (the major design consideration for ALRS stabilized layer applications) was presented in a previous project report (Reference 1).

Algorithms were developed for predicting the maximum F-15 36-kip interior loading condition flexural stresses.

$$\mathrm{Log}\,\sigma = 4.282 - 1.683 \log T + 0.105 \,\mathrm{Log}\,(E/k) \qquad (1)$$

$R^2 = 0.99 \qquad \mathrm{SEE} = 1$ psi

$$\mathrm{Log}\,\sigma = 4.371 - 1.687 \,\mathrm{Log}\, T \qquad (2)$$

$R^2 = 0.97 \qquad \mathrm{SEE} = 1.1$ psi

where:

σ = Maximum flexural stress, psi

T = Stabilized layer thickness, inches

E = Stabilized material modulus, ksi

k = Modulus of subgrade reaction psi/in.

ILLI-SLAB flexural stresses for the F-4 (27k, 265 psi) and F-15 (30k, 365 psi) can be accurately estimated by multiplying the F-15 (36k, 400 psi) stress by 27/36 and 30/36, respectively. The loading effects for the F-4 (27 kips), F-15 (30 kips), and F-15 (36 kips) are approximately linear.

3. Ultimate Load Theory Results

Meyerhof's ultimate load-carrying capacity analysis procedures can be used to predict the behavior of typical stabilized-layer pavements. An important feature of the ultimate load-carrying capacity approach is the ability to accommodate load position effects (interior, edge, corner). A graphical solution is presented in Figure 2. The major factors influencing ultimate load-carrying capacity are slab thickness and stabilized material modulus of rupture.

Meyerhof theory was used to predict the ultimate load-carrying capacity of typical stabilized-layer pavements for F-4 and F-15 loading. The data summary has been presented in a previous project report (Reference 1). Typical results for F-4 loading and a 12-inch stabilized layer are shown in Figure 3.

C-130 loading was also considered. In general, based on ultimate load theory, an ALRS pavement with adequate ultimate load-carrying capacity for F-4 traffic can accommodate a limited number of C-130 load repetitions.

4. Inverted Pavement Results

An inverted pavement section includes a surface course (either an AC layer or a nonstructural type surface treatment), a high-stability granular layer, and a stabilized-material subbase layer. The design variables are AC thickness, granular material layer thickness, strength and thickness of stabilized subbase, and subgrade modulus (E_{Ri}).

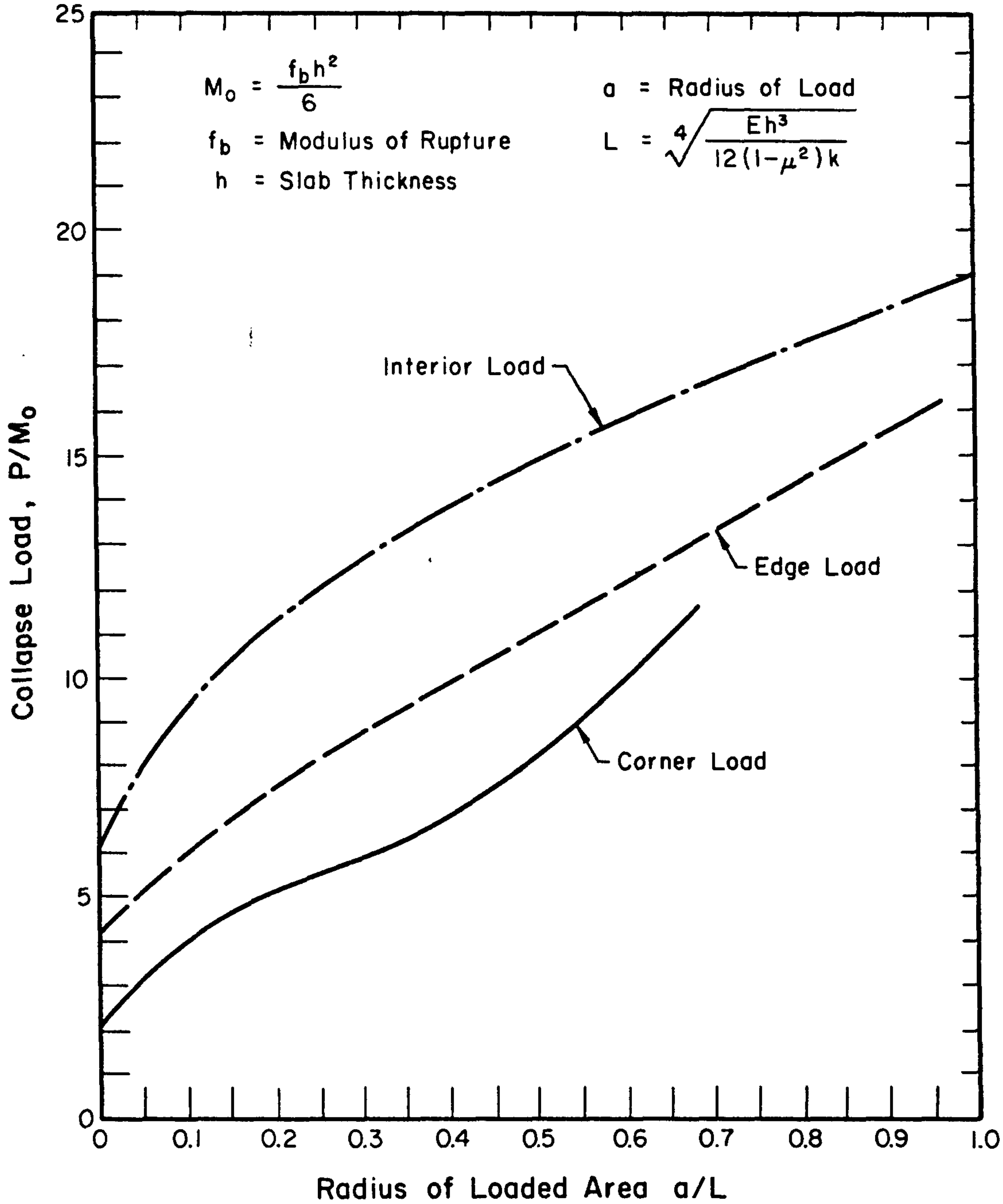

Figure 2. Graphical Solution for Meyerhof Ultimate Load Equations.

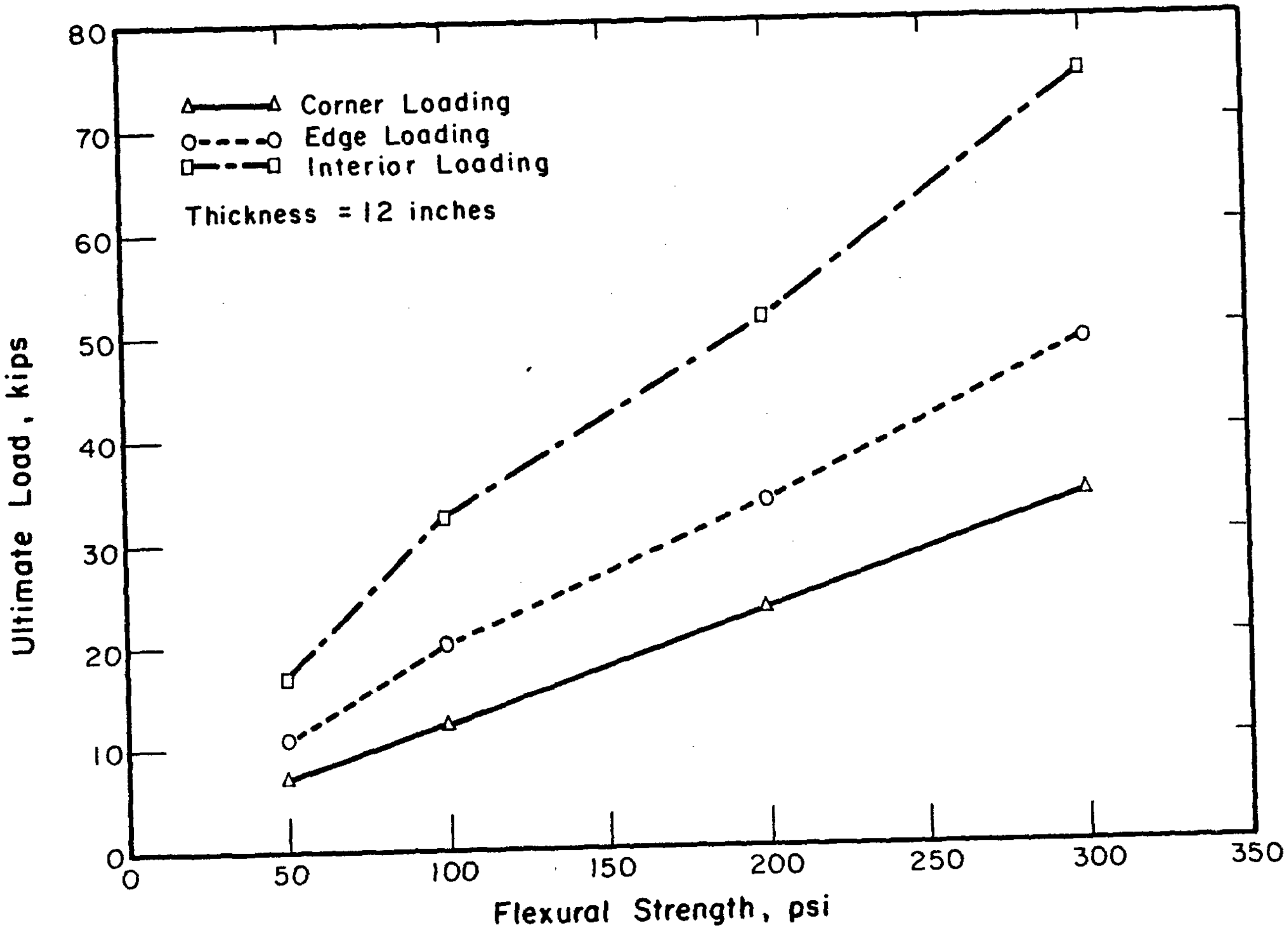

Figure 3. Ultimate Load-Strength Relations (12-inch Thickness).

The ILLI-PAVE analyses of ALRS stabilized-base sections indicated that for good-quality stabilized material the flexural stress in the stabilized base is primarily controlled by base course thickness. The surface course and granular layer of an inverted pavement section (1) alleviate reflection cracking from the stabilized subbase, (2) reduce freeze-thaw cycles in the stabilized subbase, and (3) reduce subbase layer flexural stress.

Several ILLI-PAVE analyses were made for typical ALRS inverted pavement sections. Pavement response data for F-4 and F-15 loading are summarized in Reference 1. Flexural subbase stresses for the inverted pavements were compared to the predicted flexural stresses (see Table 2) for the base course thickness only. The comparisons indicated that the combined effect of the AC and granular layer is to reduce the stabilized-subbase flexural stress to approximately 65 to 70 percent of the value for the "stabilized-base course only," condition. Practical ALRS construction considerations limit the minimum thickness of AC plus granular layers to about 6 inches (2 inch AC + 4 inches of granular material).

5. Load Placement Effects

Load placement (interior, edge or corner) influences pavement structural response. Flexural stress in the stabilized-base course is the controlling design criteria. For given conditions (material strength and modulus, subgrade support, base thickness, loading) flexural stresses are lowest for interior loading and are greater for corner and edge locations.

Stabilized-base courses are not continuous slabs. Transverse shrinkage cracks and longitudinal construction joints break the continuity of the stabilized layer. The critical design location for the aircraft load is at one of the cracks or joints where the maximum stress in the stabilized layer occurs.

Cemetitious base materials typically develop a transverse-shrinkage cracking pattern following construction. The crack-interval spacing and the crack width are related to stabilized base strength. Higher-strength materials display long intervals between cracks and the crack widths are wider. Lower-strength materials have shorter intervals between cracks and the crack widths are less.

TABLE 2. ILLI-PAVE DATA FOR INVERTED PAVEMENTS

Loading		Thickness, in.		Stabilized Subbase				
A/C	Wheel Load, Kips	AC*	Crushed Stone	Thickness, inches	Modulus, ksi	Surface Deflection, mils	Stabilized Layer Flexural σ, psi	Maximum Subgrade Deviator σ, psi
F-4	27	2	6	10	1,400	29	159	3.2
F-4	27	2	6	10	2,000	27	169	2.6
F-4	27	-	6	8	700	38.4	213	5.9
F-4	27	-	6	10	700	34.1	160	4.9
F-4	27	-	6	12	700	31.3	117	4.1
F-4	27	-	6	14	700	29.7	91	3.5
F-4	27	-	8	12	1,400	32	118	2.6
F-4	27	-	8	12	2,000	31	123	2.2
F-15	30	2	6	9	2,000	41.5	260	2.5
F-15	30	2	6	12	2,000	38.0	160	1.8
F-15	30	2	6	15	2,000	36.2	100	1.4
F-15	30	2	9	12	2,000	43.1	140	1.7
F-15	36	2	6	9	2,000	48.1	310	2.8
F-15	36	2	6	12	2,000	43.9	185	2.1
F-15	36	2	6	15	2,000	41.8	120	1.6
F-15	36	2	9	12	2,000	49.5	165	2.0

Notes

* *Asphalt Concrete Modulus* = 500 ksi
Medium Subgrade for all F-4 Sections and Soft Subgrade for all F-15 Sections

Longitudinal construction joints are also present in a stabilized-base course. Typical base paving widths are 10-15 feet.

Corner loading conditions develop at locations where longitudinal and transverse cracks intersect. For joint locations removed from the intersection points, edge-loading conditions prevail. Construction width layout can be arranged to develop an aircraft trafficking pattern resulting primarily in interior and edge-loading conditions.

It is necessary to consider load placement effects in thickness design. Based on the assumption that longitudinal construction joints will be properly located, it is proposed that interior and edge loading be considered for ALRS stabilized pavement thickness design. The ILLI-PAVE stress-dependent finite element program is only for interior-loading conditions. Meyerhof ultimate load theory considers interior, corner, and edge loading. ILLI-SLAB (a finite element model) has no restrictions on load placement and can also accommodate varying degrees of load transfer between adjacent slab segments.

Phase I (Reference 1) results indicated that for routine thickness design, a stress intensity factor can be applied to the calculated interior flexural stress to estimate the increased edge-loading stresses. The ILLI-PAVE structural model was recommended for calculating the interior flexural stress. A stress intensity factor of 1.5 is suggested for ALRS design purposes.

6. Summary - Phase I

It was proposed that ALRS stabilized pavements be designed using an "intact slab" approach. Although the pavements develop longitudinal and transverse cracks shortly after construction, the thickness of the stabilized layer should be adequate to prevent significant additional cracking under aircraft loading. Thickness design should be based on edge-loading conditions.

It was recommended that a stress intensity factor of 1.5 be used for initial ALRS design. If ILLI-PAVE interior radial tensile stresses are increased by 50 percent, the predicted stresses will probably be conservative (predicted stress > actual stress).

B. PHASE II - ENVIRONMENTAL FACTORS

Temperature (primarily freeze-thaw) and moisture effects are essential ALRS design considerations. The primary freeze-thaw (F-T) effects are decreased stabilized-base material strength and thaw-softened subgrade soil (decreased modulus, decreased strength).

A climatic model previously developed at the University of Illinois was used to establish climatic effects for ALRS pavements. A comprehensive discussion of the background development, and application of the climatic model is presented in a project report (Reference 1).

Input data for Ramstein AB, West Germany were used to quantify environmental effects for typical ALRS pavement sections. The idealized freeze-thaw cycle shown in Figure 4 was developed for the Ramstein AB data. Data for number of F-T cycles are presented in Table 3. A freeze-thaw cycle-recurrence interval plot is shown in Figure 5 for Ramstein AB.

Depth-of-frost-penetration data were also developed for the Ramstein AB data. Maximum depth-of-frost-penetration data for typical ALRS pavements are summarized in Table 4.

Freeze-thaw durability testing was conducted in a special testing unit previously designed and constructed at the University of Illinois. The freeze-thaw testing unit accurately simulates frost action. A cement-stabilized sandy gravel (the material utilized in the ALRS stabilized test sections at the Waterways Experiment Station, Vicksburg, Mississippi) was evaluated. The typical freeze-thaw cycle for Ramstein AB was utilized. The residual strength (strength following freeze-thaw cycles) - initial strength relation shown in Figure 6 was developed.

The concepts, procedures, and data developed in this program can be used to characterize the effect of environmental factors on ALRS pavements.

C. PHASE III - DEVELOPMENT OF PRELIMINARY ALRS STABILIZED SOIL PAVEMENT ANALYSIS SYSTEM (SPAS)

A preliminary proposed procedure for designing ALRS stabilized pavement sections was developed. Inputs required to establish a stabilized base thickness for an ALRS pavement (F-4 loading) are the

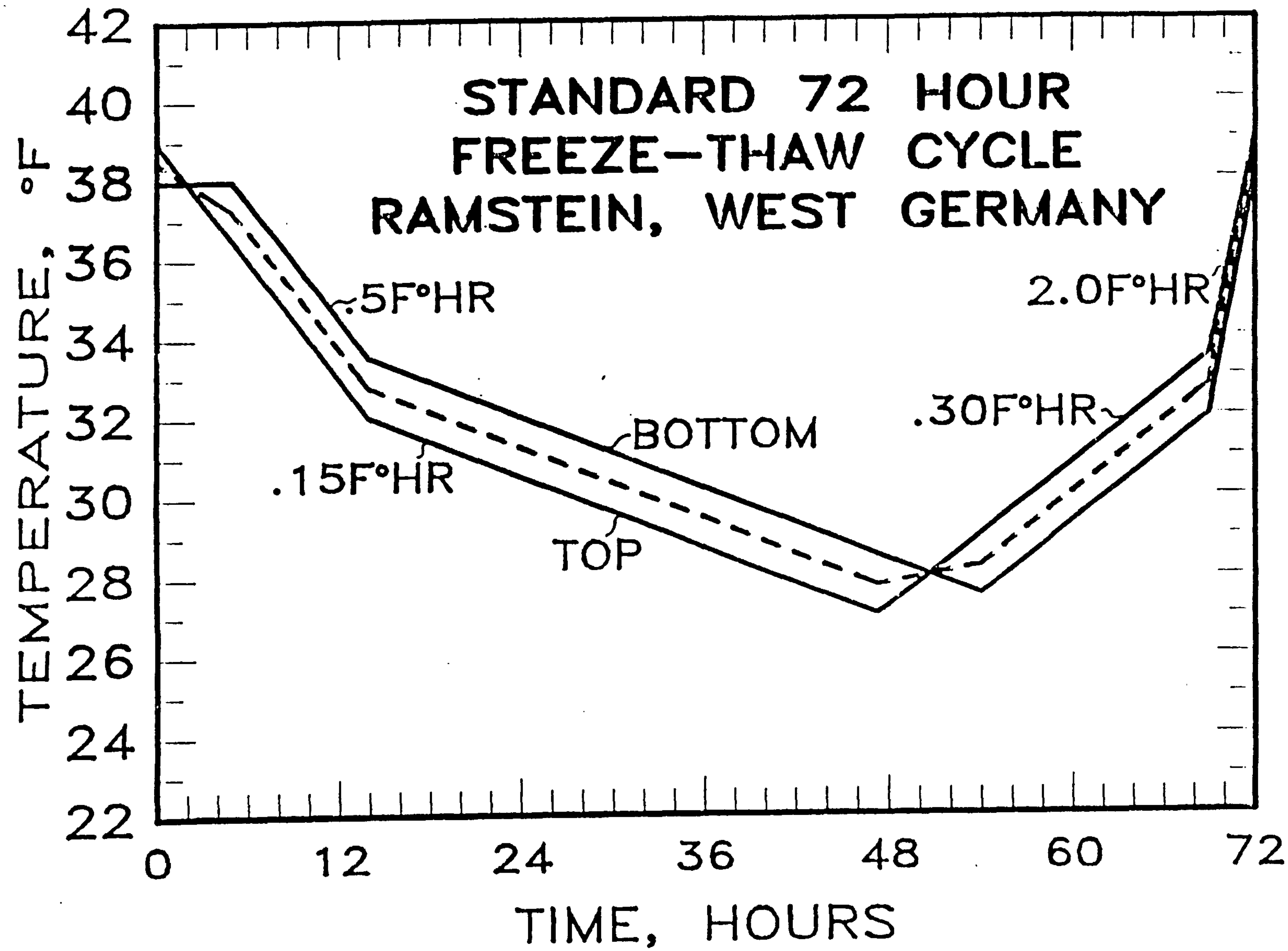

Figure 4. Standard Freeze-Thaw Cycle for Ramstein AB, West Germany.

TABLE 3. NUMBER OF FREEZE-THAW CYCLES PER YEAR

Pavement System			
AC Surface:	2 in.	2 in.	0 in.
Stab. Base:	8 in.	16 in.	8 in.
Winter Period	Number of F-T Cycles 2 in. into Stabilized Base		
1952-1953	0	0	-
1953-1954	6	7	-
1954-1955	0	0	-
1955-1956	7	8	-
1956-1957	2	3	-
1957-1958	0	0	-
1958-1959	0	0	-
1959-1960	3	3	-
1960-1961	0	0	-
1961-1962	4	5	-
1962-1963	12	13	21
1963-1964	13	15	16
1964-1965	0	1	-
1965-1966	5	6	-
1966-1967	0	0	-
1967-1968	2	2	-

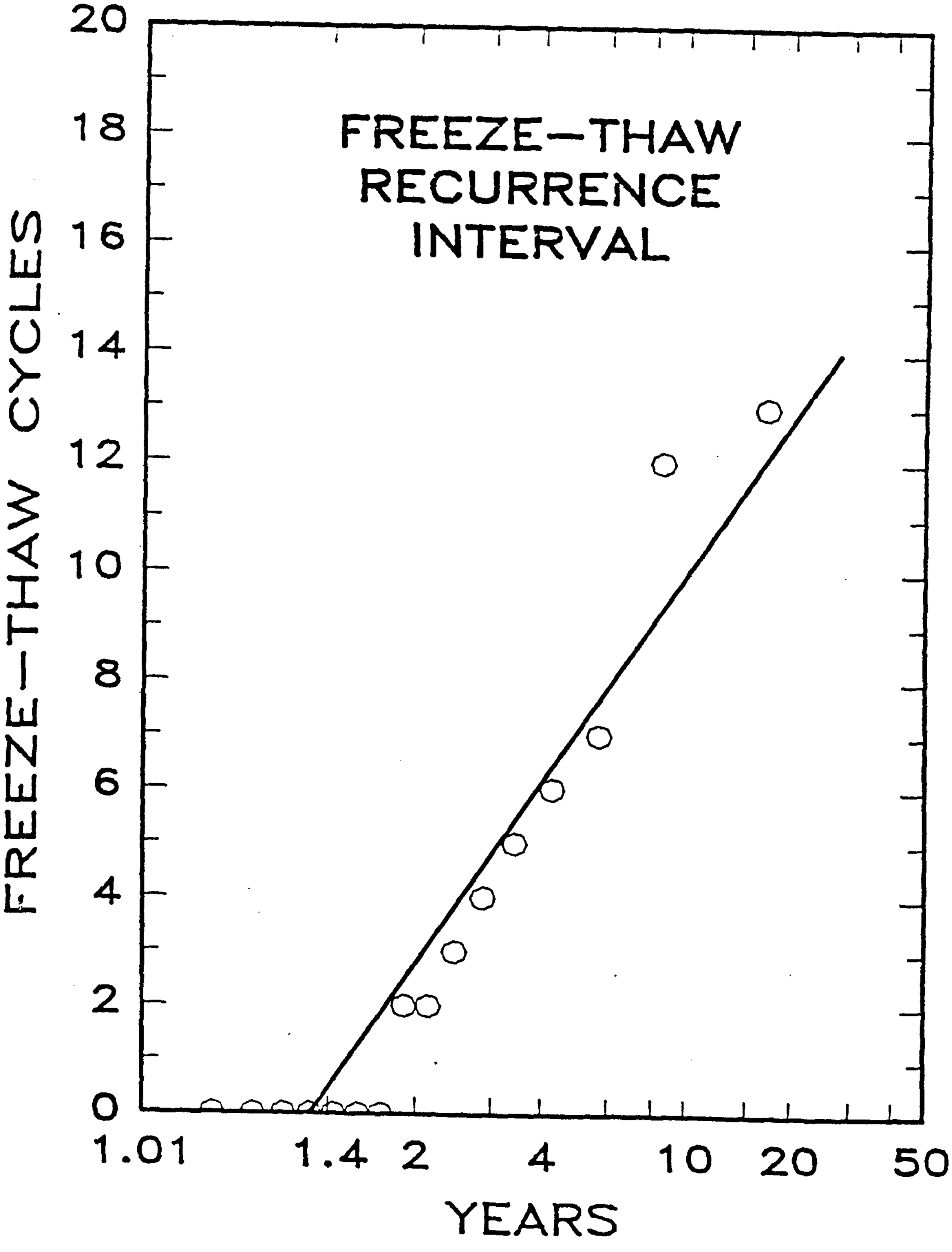

Figure 5. Freeze-Thaw Cycle Recurrence Interval.

TABLE 4. MAXIMUM DEPTH OF FROST PENETRATION EACH YEAR

Pavement System			
AC Surface:	2 in.	2 in.	0 in.
Stab. Base:	8 in.	16 in.	8 in.
Winter Period	Maximum Depth of Frost Penetration, in.		
1952-1953	3.1	3.2	-
1953-1954	15.9	19.9	-
1954-1955	3.4	3.5	-
1955-1956	17.4	21.5	-
1956-1957	5.8	5.8	-
1957-1958	2.6	2.7	-
1958-1959	3.0	3.0	-
1959-1960	7.9	8.0	-
1960-1961	3.7	3.8	-
1961-1962	9.6	9.4	-
1962-1963	23.5	28.0	25.4
1963-1964	13.2	14.7	14.0
1964-1965	4.0	4.6	-
1965-1966	14.7	18.3	-
1966-1967	2.9	2.9	-
1967-1968	6.0	7.0	-

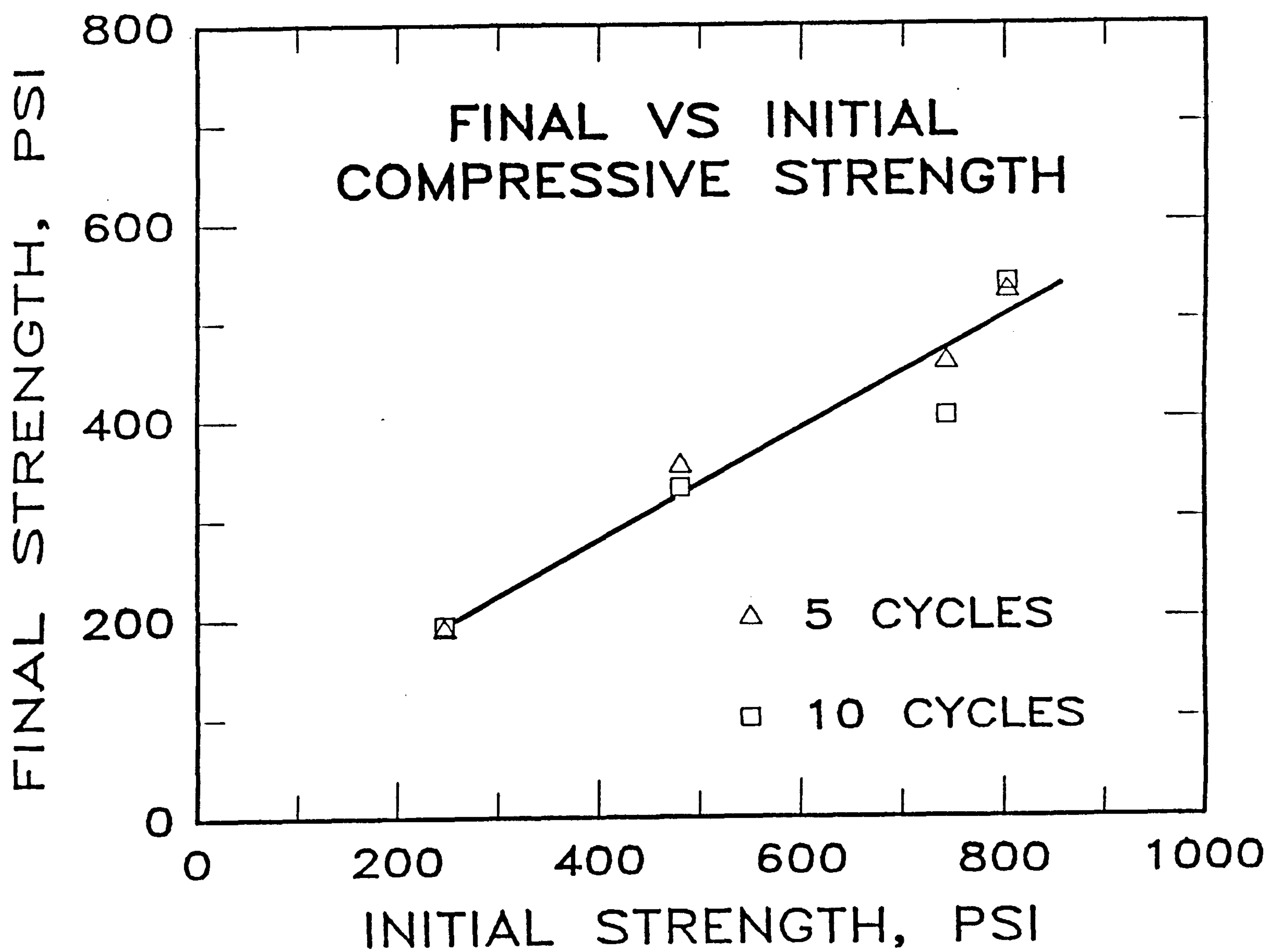

Figure 6. Residual Strength Versus Initial Strength.

field strength of the stabilized material and the E_{Ri} (measure of resilient modulus) of the subgrade.

The structural analysis procedure assumes the stabilized layer is an "intact slab." The major factor influencing the flexural stress is stabilized-base layer thickness.

Field-curing conditions (time, temperature), field-mixing variability, field density, and cyclic freeze-thaw factors should be considered in estimating the residual strength of a stabilized material. The factors can be quantified, using procedures included in a previous project report (Reference 1).

The lowest anticipated subgrade E_{Ri} value should be utilized in the thickness design process. The major factors influencing the resilient moduli of fine-grained soils are texture, plasticity, and moisture content. Freeze-thaw drastically reduces (sometimes by a factor of 2 to 4) the resilient modulus. Silty and lower PI soils (ML, MH, CL, ML-CL) are more moisture-susceptible and CH type soils suffer a larger resilient modulus loss with freeze-thaw action. Thus, for "worst-scenario" conditions, all fine-grained soils should be assigned a "low" E_{Ri} value for ALRS pavement design. Suggested design E_{Ri} values for various Unified soil classes, water table conditions, and frost effects are shown in Table 5.

Stabilized-base thickness is established by comparing the stabilized-material design flexural strength with the estimated F-4 edge-load flexural stress. The estimated edge-load flexural stress is 50 percent greater than interior load stress calculated from ILLI-PAVE.

The stress ratio (edge-load flexural stress/design flexural strength) is used to predict fatigue life. If the fatigue life is sufficient (greater than anticipated traffic), the thickness is satisfactory. The stress ratio should not exceed 0.65 (factor of safety = 1.5).

If an AC surface course is used as a structural layer, the required stabilized-base thickness can be reduced. AC surface thickness in excess of 2 inches is not normally required. A thickness less than 1 inch is of little structural value. For a 2-inch AC surface the stabilized-base thickness can be reduced by 1 inch.

TABLE 5. SUGGESTED SUBGRADE VALUES FOR ALRS DESIGN

Unified Soil Class	Design Subgrade E_{Ri}, ksi: High Water Table* — With Frost Penetration	High Water Table* — Without Frost Penetration	Low Water Table** — With Frost Penetration	Low Water Table** — Without Frost Penetration
ML,MH,CL,ML-CL	2.0	4.0	3.0	6.0
CH	2.0	5.0	3.5	7.0

* Water table seasonally within 24 inches of subgrade surface.

** Water table seasonally within 72 inches of subgrade surface.

As a final design check, the Meyerhof ultimate load-carrying capacity (edge-loading condition) is calculated. The pavement thickness is the thickness of the stabilized base or the stabilized-base thickness plus 1 inch if a 2-inch AC surface is used. The ultimate load capacity for an F-4 load should be at least 40 kips.

For inverted pavement design, use the design concept presented above modified for the stress reduction affected by the AC and granular base layers. The controlling design parameters are still the stabilized base flexural stress and fatigue. For combined thicknesses of AC surface and granular base of at least 6 inches, stabilized base-flexural stress is approximately 65 percent of the stress estimated for the stabilized-base thickness only.

ALRS stabilized pavement sections designed in accordance with the proposed F-4 procedures will accommodate the limited (25 passes) C-130 traffic. Increased C-130 passes should be considered in a more detailed structural analysis.

Increased F-15 loading (30-kip and 36-kip wheel loads) will decrease the 1.5 safety factor recommended for the F-4 design section. The approximate safety factors for the F-15 are 1.3 for 30-kip loading and 1.1 for 36-kip loading. Limited F-15 traffic can be accommodated by an ALRS section designed for F-4 traffic.

D. PHASE IV - PAVEMENT TEST SECTION REVIEW

Eleven ALRS pavement test items containing stabilized material layers were constructed at the Waterways Experiment Station, Vicksburg, Mississippi. The University of Illinois participated in the design of the ALRS test pavements, using the SPAS. WES was directed by USAF to build the test items and conduct field traffic testing.

The test items were subjected to simulated channelized F-4 passes until failure or 1000 passes. Nine two-layer cement-stabilized pavement test items of different strength and thickness and two inverted pavement test items containing crushed stone base courses and stabilized material subbase courses were constructed on a CBR 5-6 subgrade. Stabilized material layer thickness was selected to provide structural response and performance data for failure pass levels ranging from less than 100 to over 1000 passes.

The data collected from laboratory materials testing and field measurements are published in Reference 3 and were the focus of the Phase IV effort. Additional laboratory testing of the stabilized materials and subgrade soils was conducted at the University of Illinois. The data are reported in Reference 4.

The field data analyzed included Falling Weight Deflectometer (FWD) load-deflection data, surface-cracking and profile measurements, and item center pass deflection and cumulative permanent deformation.

Stabilized material layer modulus was back-calculated, using the FWD data. First-pass predicted structural response was determined using ILLI-PAVE, a stress-dependent finite element computer program, and ILLI-SLAB, a finite element computer program for rigid pavements with cracks or joints. The test items were thin by conventional design standards and predicted first-pass stress ratios in the stabilized material layers were greater than 1. The applicability of Meyerhof ultimate load theory was considered.

Item performance was divided into three phases, explaining the development and propagation of the observed cracks.

> <u>Phase I</u> begins with the initial condition of the pavement and ends with the development of load-related longitudinal cracking along the edges of the traffic lane.
>
> <u>Phase II</u> includes continued lengthening and "working" of the load-related longitudinal cracks.
>
> <u>Phase III</u> begins with the development of transverse ladder cracks in the traffic lane and ends with the load-cart punching through the CAM layer into the subgrade.

The various phases are illustrated in Figure 7.

Transfer functions were developed, relating predicted first-pass crack-stress or strain ratios to passes to functional failure.

Phase IV findings applicable to both two-layer and inverted ALRS pavements containing a stabilized material layer as the primary load-carrying pavement course are presented below.

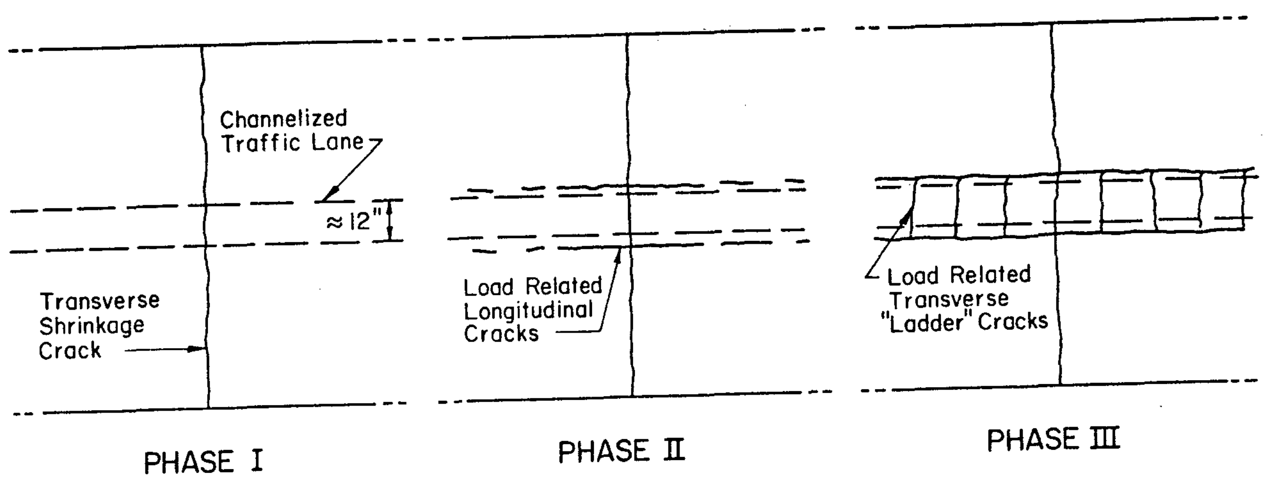

Figure 7. Phases of Performance, Two-Layer Pavement Items.

1. The mechanistic approach to the design and analysis of ALRS pavements containing stabilized material layers is validated. Important pavement section parameters affecting response and performance can be identified and performance can be predicted, using appropriate transfer functions.
2. Critical pavement response occurred at a transverse shrinkage crack. A crack load transfer efficiency (LTE) of 30 percent was typical. Increasing the interior flexural (tensile) stress in the stabilized-material layer by 50 percent is a good estimate of the crack tensile stress for a 30 percent LTE.
3. Performance is dominated by the thickness of the stabilized material layer. Strength of the stabilized material for pavements with a stress ratio greater than 1 does not have a major effect on performance.
4. ALRS design for passes to functional failure of 1000 or less should be based upon an intact slab analysis where the predicted first-pass crack-stress ratio is less than one. The relationship between thickness, modulus, strength, LTE and subgrade strength in partially cracked stabilized material layers is too complex to model.

Findings applicable to two-layer ALRS pavements containing a rigid stabilized-material layer are presented below.

1. If the applied wheel-load-induced predicted crack-stress ratio is greater than one, but the load is less than twice the predicted Meyerhof edge collapse load, the ALRS pavement has "reserve performance capability" and will give acceptable performance for a limited number of passes. The lower the predicted stress ratio the better the performance.
2. Conservative transfer functions were developed relating predicted first-pass crack-stress or strain ratios to pavement performance.
   a. The transfer functions were developed for stress and strain ratios greater than one, F-4 aircraft loading and cohesive soil subgrades of CBR 5-6.

b. Transfer functions developed using stress and strain ratios greater than one do not give the same strength, modulus, thickness, and performance relationships. This is not unexpected since the relationship between the parameters affecting crack propagation and performance in a cracked pavement is very complex. However, both transfer functions predict approximately 1000 passes to functional failure for first-pass crack-stress or strain ratios near 1.

c. The transfer functions developed are more applicable for ALRS pavement analysis than for design. Design of new ALRS pavements should be based on a mechanistic approach and transfer functions based on stress ratios less than 1 and appropriate shift factors.

3. Distributed traffic will initiate many small cracks at the bottom of the stabilized layer in pavements with a predicted first pass crack stress ratio greater than one. The effect of these numerous cracks at the bottom of the stabilized material layer on structural response and performance cannot be determined. Therefore, for pavements with a predicted first-pass crack-stress ratio in the stabilized material layer greater than one, all traffic should be considered channelized in a single traffic lane.

4. The relationship of thickness, modulus and strength of the stabilized material layer for a predicted Meyerhof edge-collapse load twice the applied wheel load of the F-4 is nearly identical to that required to produce a predicted first-pass crack-stress ratio of 1. Test items with a predicted Meyerhof edge collapse load twice the 27 kip F-4 load performanced well.

5. ALRS pavements containing cement-stabilized materials require a wearing course on the surface of the stabilized material to prevent tire abrasion. The wearing course need not provide additional load-carrying capability.

The following findings are applicable to ALRS inverted pavements containing a rigid stabilized material subbase course.

1. The thickness of the stone base course should be approximately 4 inches for thin asphalt concrete wearing courses (less than 1.5 inches). The maximum stress ratio in the stone base course occurs at mid-depth in the stone layer where the confining stress is the lowest. Increasing the stone base course thickness reduces confining stress at mid-depth, producing a softer stone response, increased surface deflection, increased asphalt concrete strain, and increased permanent deformation in the stone layer.
2. The stress ratio in the stabilized material subbase course is more affected by the thickness of the subbase than the thickness of the stone base course. An inch of subbase has a much greater effect on the subbase stress ratio than does an inch of stone base.
3. The crushed stone base course alleviated crack propagation in the stabilized material subbase course. Reduced rates of crack propagation to the asphalt concrete surface of the item and better item performance for the same stabilized material stress ratio were noted for the inverted sections.

SECTION III

ALRS PAVEMENT DESIGN AND EVALUATION

A. INTRODUCTION

A preliminary SPAS was developed in Phase III and is described in Section II of this report. An "intact slab" approach based on ILLI-PAVE analyses and Meyerhof ultimate load concepts is recommended. Extensive analyses of the WES ALRS test sections (Reference 4) validated the basic rudiments of the preliminary SPAS proposals and facilitated further SPAS development and improvement. The ALRS test section data were particularly beneficial in the development of transfer function concepts relating ALRS pavement response to performance.

SPAS is applicable to both the design of new and the evaluation of existing ALRS pavements containing stabilized material layers. The processes of design and evaluation are similar and include many of the same steps. In design, the strength, thickness and modulus of the stabilized material layer are not fixed but can be varied over a broad range to determine the most economical pavement structure. In evaluation, the strength, thickness and modulus of the stabilized material layers are determined/assumed based on existing conditions. In both situations, a mechanistic analysis of the resulting pavement structure is performed to determine the response parameters of interest (stress, strain and deflection). The response parameters are then used to predict performance through appropriate transfer functions.

B. SUGGESTED ALRS PAVEMENT DESIGN CONCEPT

The activities and findings reported in this research (References 1,4) support the ALRS pavement design concept presented below.

1. Design for a minimum of 1000 passes. The variability in pavement performance is large for functional failures occurring at less than 1000 passes.
2. Base the structural analysis on an intact slab condition with only transverse shrinkage cracks and longitudinal construction joints. Locate longitudinal construction joints so the center of the main

gear traffic pattern is at least 3-4 feet from a longitudinal joint.

3. Increase the ILLI-PAVE maximum predicted interior flexural (tensile) stress at the bottom of the stabilized layer (Table 1) by 50 percent to estimate the maximum crack flexural (tensile) stress acting parallel to the transverse shrinkage crack.

4. Predict performance using available transfer functions for stabilized materials. In design, limit the crack stress ratio to less than one. Use the suggested fatigue transfer function in Figure 8, and apply appropriate shift factors to estimate field performance. Control the stress ratio in the stabilized material layer by varying the thickness of the stabilized material layer. In evaluation, for calculated stress ratios greater than one, use Figure 9 as a guide in predicting potential ALRS pavement field performance. Note that the Figure 9 transfer function is only for "medium" subgrade conditions similar to the WES test sections.

5. Check the mechanistically designed ALRS pavement section against the ultimate load criteria. Good performance is obtained if the Meyerhof predicted edge collapse load is at least twice the applied wheel load. Adjust the pavement section properties so stress ratio and ultimate load criteria are both met.

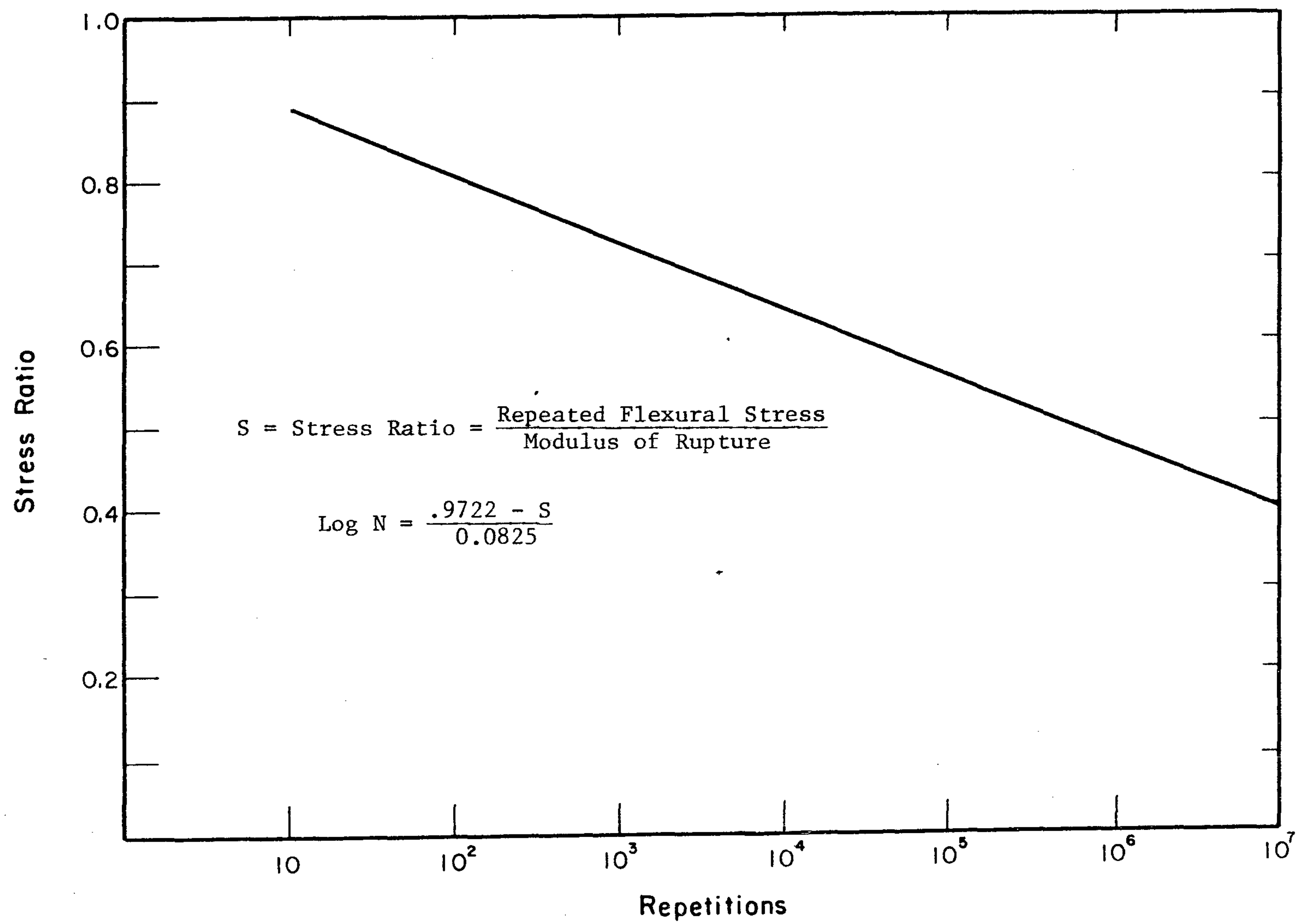

Figure 8. Recommended Stress Ratio-Fatigue Relations for Cement-Stabilized Materials.

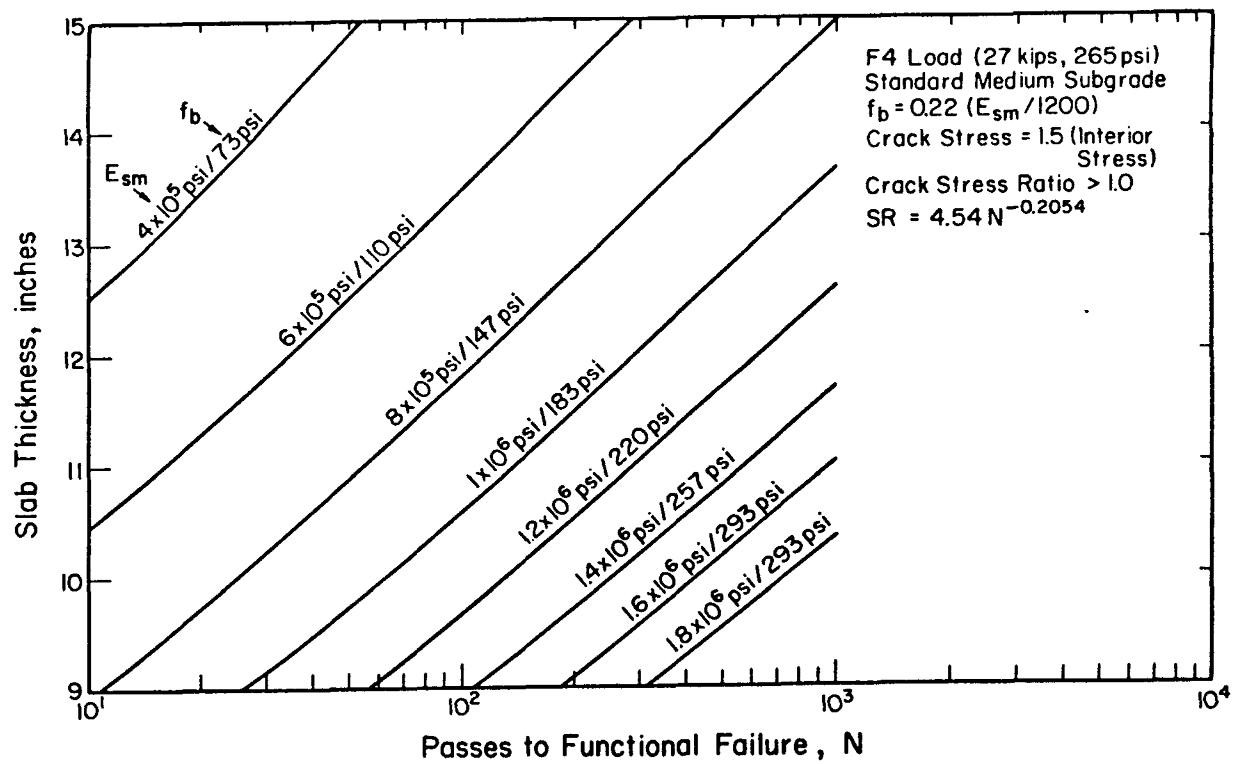

Figure 9. Performance as a Function of Slab Thickness, Modulus and Strength Using Stress Ratio Transfer Function (F-4 ILLI-PAVE Data Base).

SECTION IV

SUMMARY

An "ALRS Stabilized Material Pavement Analysis System" (SPAS) is proposed. An "intact slab" approach based on ILLI-PAVE analyses and Meyerhof ultimate load concepts is recommended. A design process for inverted ALRS pavements is also presented. The study of the WES Test Section data indicated the validity of SPAS and facilitated the development of transfer function concepts relating ALRS pavement response to performance.

Inputs required to establish the stabilized base thickness for an ALRS pavement (F-4 loading) are the field strength of the stabilized material and the E_{Ri} (measure of resilient modulus) of the fine-grained subgrade. A properly designed ALRS pavement for F-4 loading can accommodate a reduced number of C-130 and F-15 load applications. The SPAS thickness design concepts (based on an intact slab approach) are applicable to a broad range of cementitious-stabilized materials (soil-cement, lime-fly ash-aggregate, soil-lime mixtures, similar high-strength and modulus materials).

It is emphasized that adequate material quality control and construction procedures must be developed and implemented for field construction. Stabilized mixture uniformity (percent stabilizer, thoroughness of mixing, moisture content, etc.), placement (layer thickness, compacted density), and curing (time, temperature, moisture maintenance) are some critical specification items.

ALRS stabilized base pavement constructed in accordance with SPAS should be monitored. Nondestructive testing, condition survey (cracking, rutting, etc.), environmental factors (moisture-temperature), stabilized material strength, and traffic data are pertinent items. Nondestructive testing data for "critical" subgrade support conditions are of particular interest.

LIST OF REFERENCES

1. Thompson, M. R. and Dempsey, B. J., Development of a Preliminary ALRS Stabilization Material Pavement Analysis System (SPAS), Technical Report ESL-TR-83-84, US Air Force Engineering and Services Center, Tyndall AFB, Florida, March, 1984.
2. Ioannides, A. M., Donnelly, J., Thompson, M. R., and Barenberg, E. J., Analysis of Slabs-on-Grade for a Variety of Loading and Support Conditions, Report to Air Force Office of Scientific Research (AFOSR), Air Force Systems Command, Bolling AFB, D.C., December, 1984.
3. Styron, C. R., Performance Data for F-4 Operations on Alternate Launch and Recovery Surfaces, Technical Report ESL-TR-83-46, U.S. Air Force Engineering and Services Center, Tyndall AFB, FL, July, 1984.
4. Costigan, R. R. and Thompson, M. R., "Response and Performance of Alternate Launch and Recovery Surfaces," Technical Report ESL-TR-84-25, US Air Force Engineering and Services Center, Tyndall AFB, FL, January, 1985.